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Published in:
Proceedings of ROOMVENT 2014, 13th SCANVAC International Conference on Air Distribution in Rooms

Publication date:
2014

In: Proceedings of the 13th International Conference on Air Distribution in Rooms, Roomvent2014, 19-22 October, Sao Paulo, Brazil, paper ID193.

IMPACT OF PERSONALIZED VENTILATION COMBINED WITH CHILLED CEILING ON EYE IRRITATION SYMPTOMS

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Abstract

Personalized ventilation (PV) improves inhaled air quality, because it provides fresh air to each workstation and directly to occupant's breathing zone. The PV alone can be used for room ventilation when applied in conjunction with ceiling radiant cooling system, which removes sensible heat loads from the space. Combining PV with chilled ceiling may be an effective way to provide thermal comfort in rooms at air temperature higher than the recommended in the standards upper limit of 26°C (category II), because the operative temperature will be lower. However, combination of high air temperature, elevated air movement toward face and increased radiant cooling may have impact on the eye symptoms.

Twenty four human subjects participated in experiments with PV combined with chilled ceiling system (CCPV) and with mixing ventilation (MV) combined with chilled ceiling (CCMV). In the experiments with PV participants were provided with control of supplied air flow rate and direction. Room air temperature was kept at 26°C and 28°C. Relative humidity in the chamber was not controlled but was monitored and it varied between 20% and 30% during the experiments. Supplied air temperature (by PV and MV) was 3 K lower than room air temperature. Average supply/return water temperature for chilled ceiling was 15,5/16,8°C at room air temperature of 26°C and 19,5/20,6°C at 28°C. The total exposure time was 3 h (with 0,5-h. acclimatization period). During the experiment subjects performed typical office tasks at workstations with computers. Exposure included also a higher activity level office work for a period of 25 min outside computer workstations.

The influence of the environment on eye symptoms was assessed by subjective votes and objective measurements. Subjects reported on the eye irritation and the intensity of eye dryness 6 times throughout each experiment. Eye tear film samples were taken at the beginning and the end of the exposure. The blinking rate was analysed in the beginning and at the end of exposures. The preliminary results of the analyses reveal that the environment subjects were exposed to had an impact on their subjective and physiological response.

Keywords: radiant cooling, personalized ventilation, eye symptoms, tear film stability, blinking rate

1 Introduction

Today HVAC engineers meet the important challenge of creating comfortable indoor environment conditions in spaces at low energy use. Personalized ventilation (PV), in a contrary to traditional mixing ventilation or displacement ventilation, delivers fresh air directly to occupants' breathing zone and increases quality of inhaled air (Kaczmarczyk et al., 2004). Its' documented improvement of occupants' comfort at elevated room air temperature (Melikov et al., 2013b) and potential for substantial energy savings (Schiavon and Melikov, 2008; Schiavon et al., 2010). Limitation in possible supply airflow rates through this systems requires a separate cooling system at high heat loads to keep thermal condition in the space. Results of previous research (Lipczynska et al., 2014a, b) proved that PV combined with radiant chilled ceiling can operate as a single ventilation system. Previous studies (Schiavon et al., 2010) show that PV combined with mixing or displacement ventilation can bring energy-savings compared to total volume ventilation systems alone. Due to higher cooling energy efficiency of radiant systems compared to air systems it may be expected that PV combined with chilled ceiling may be even more energy-efficient than when it is combined with mixing ventilation.

One of the most common sick-building syndrome symptoms in the offices are related to eyes. From many ocular symptoms (e.g. excess tearing, itching, ocular fatigue, redness, "sandy" sensation), the eye dryness and irritation are the most frequent complaints (Wolkoff, 2005; Wolkoff et al., 2006; Wolkoff et al., 2003). Among other factors, environmental conditions influence the tear dynamics. Abnormal tear production, distribution or evaporation leads to ocular irritation. Increased air temperature and decreased relative humidity decrease pre-corneal tear film (PTF) stability as a result of increased aqueous tear evaporation (Wolkoff, 2008; Wolkoff et al., 2006). Furthermore the evaporation increases at the elevated air velocity in the ocular region. Other research indicates the PTF break-up time decrease at exposure to velocity of 1,0 m/s but not to 0,5 m/s (Wyon and Wyon, 1987). The air temperature, relative humidity and velocity influence the blinking frequency (BF) as well. Velocities above 1 m/s results in increase of BF to keep balance in corneal moisturizing during relaxing ocular activity. However this influence is negligible during visual demanding tasks like computer work. Despite the drying effect and physiological need of BF increase, sight and attention keep focused on the task, and result in 2-3 times lower BF than with relaxed conditions (Skotte et al., 2007; Wolkoff, 2008). PV provides elevated air movement for which mostly face is exposed. Together with increased radiant heat exchange it can be one of the causes of eye irritation and occupants discomfort. Previous studies on PV showed increase of eye dryness perception in time, but without significant increase in eye irritation (Kaczmarczyk et al., 2010; Melikov et al., 2013a; Melikov et al., 2013b). Other research revealed that facially applied flow under individual control did not result in BF change (Melikov et al., 2011). Furthermore, supplying clean air can compensate increase of BF in warm and humid environment.

This paper presents influence of personalized ventilation combined with chilled ceiling on eye irritation symptoms based on subjective and psychological measurements. Evaluation of the thermal conditions and perceived air quality of the environment created by the combined systems of CCPV or CCMV is presented by Lipczynska et al. (2014c).

2 Methodologies

Experiments with 24 human subjects (12 males and 12 females) were carried out in a climate chamber arranged as 2-persons office room (Figure 1). Performance of chilled ceiling combined with personalized ventilation (CCPV) and chilled ceiling combined with mixing ventilation (CCMV) systems was studied at the set-point room air temperature of 26°C and 28°C. The relative humidity was not controlled during experiments and it varied in the range of 20 to 30% between sessions. The order of conditions the subjects were exposed was randomized. One training session took place before the experiment start in order to make the subjects familiar with questionnaires, the experimental procedure and the preformed physiological measurements.

An air terminal device for PV (named round movable panel, RMP) was installed at each workstation (WS1 and WS2, Figure 1). The RMP generates laminar flow of personalized air (Bolashikov et al., 2003). The flexible arm, at which RMP was attached, allowed subjects to change its positioning (and thus the direction of the personalized flow) according to their preferences. MV used two linear diffusers mounted in the centre of the ceiling. The supply air flow rate of 26 L/s for ventilation was calculated according to the recommendations in (EN 15251, 2007) for category II as a sum of flow rate needed for removal of low-pollution from building materials, q_B = 12 L/s (0,7 L/s per m^2), and flow rate for removal of pollution from occupants, q_P (7 L/s per person). Together with adjusting RMP's position, subjects were provided with individual control of the supply airflow rate from RMP in the range of 0-13 L/s. A local diffuser (LPD) was installed in the partition between WSs (Figure 1a) and was connected with the PV system. The LPD kept constant airflow of 26 L/s supplied to the office when the subjects controlled the PV flow rate to be lower than 13 L/s. Supply air temperature was kept at all cases 3 K lower than room air temperature. There was no air recirculation in the systems. 18 radiant panels (1190x590 mm) were installed in the suspending ceiling, covering totally 75% of floor area. Average supply/return water temperature for chilled ceiling was 15,5/16,8°C at room air temperature of 26°C and 19,5/20,6°C at 28°C.

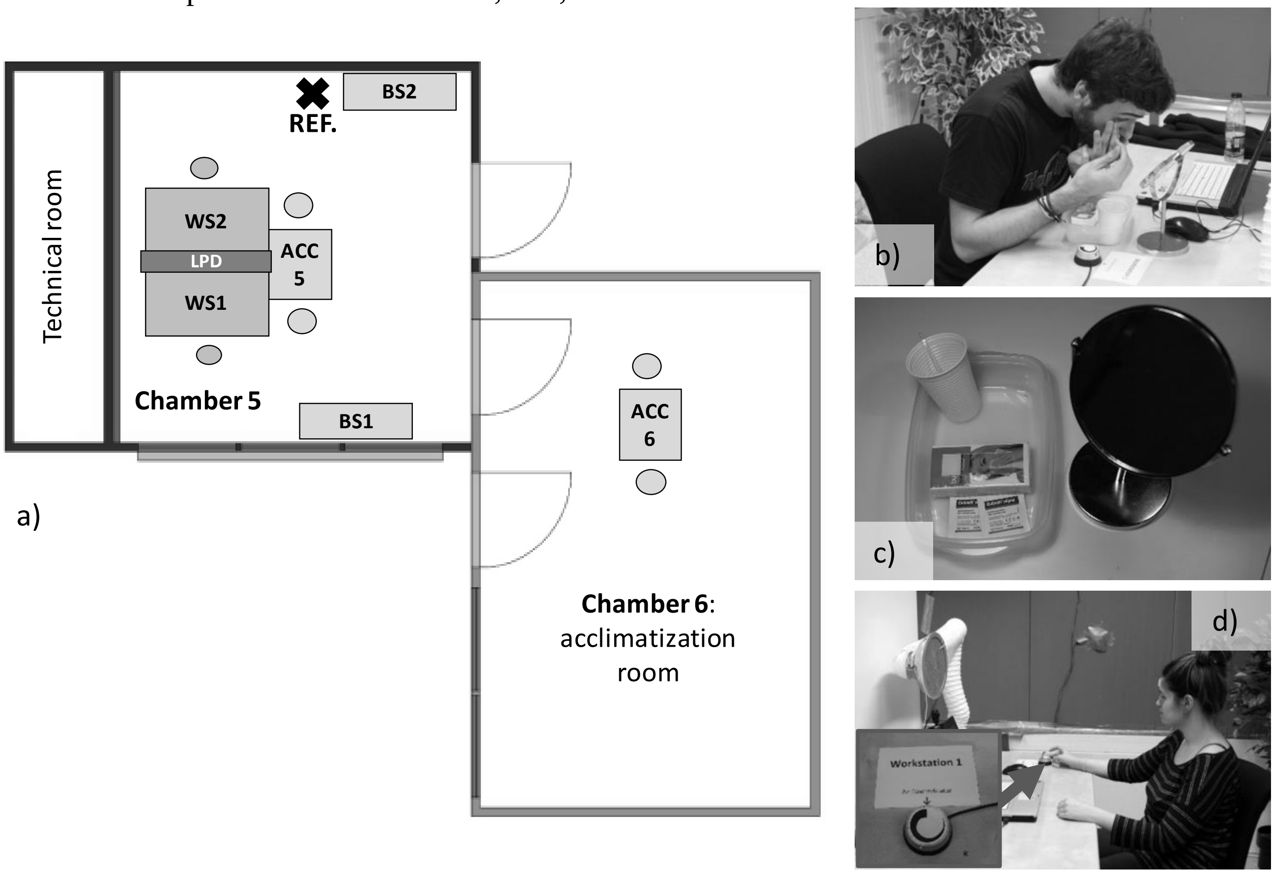

Figure 1. *Lay out of the chamber: a) plane view, b) subject taking tear film sample, c) set prepared for tear film sampling, d) PV airflow control*

Experimental procedure is shown in Figure 2. For the first 30 min subjects were exposed to the uniform environment in an acclimatization room (chamber 6) after which they moved to the experimental office room (chamber 5), where four phases of exposure took place. For assessing the tear film quality the samples of tear mucus film were taken (Figure 1b) according to procedure of tear film ferning test (Masmali et al., 2014). Participants each time were provided with a plastic box containing paper tissues, disinfection wet tissues, a laboratory glass plate and rod for tear film collection, and a hand mirror (Figure 1c). At the end of acclimatization in chamber 6 the first tear film sample was taken. It was assumed that period of 25 min is long enough for tear film recovery after subjects' previous activity, e.g. biking. Tear film samples were analysed under the microscope, where the pictures of the crystallization patterns were taken. Patterns were examined visually and sorted into five categories according to the closeness and branching frequency of the fern patterns (Masmali et al., 2014). Temperature in both chambers was identical. Adaptation process continued for the next 15 min in chamber 5 (Phase I) at the desk next to the WSs (ACC 5 in Figure 1). At this location the first blinking rate recording took place by web cameras. When seated at the WSs subjects performed computer tasks. For the whole exposure at WSs the facial area was recorder for determining the blinking frequency (BF) analyses, but only first and last 15 min were analysed. Video recording were examined in a video editing programme (1,5x speed motion) for manual blink counting. Computer work at WSs was distinguished as short work period (Phase II), and long work period (Phase IV). During Phase II subjects performed walking activity outside WSs. After the whole experiment was ended, the second tear film sample was taken.

During each experiment subjects filled in totally 10 questionnaires. This paper focuses on influence of the systems on eye symptoms. Subjects reported on the eye irritation and the intensity of eye dryness 6 times: once in the acclimatization room and 5 times during the exposure. The eye dryness was evaluated on a continuous scale ranging from "no dryness" (0%) to "overwhelming dryness" (100%). The eye irritation was reported by "yes" or "no". Air movement assessment included questions about perceiving air movement ("yes" or "no"), air movement acceptability ("yes" or "no) and preferred air movement change ("more air movement", "no change" or "less air movement"). Air dryness was assessed with continues scale ranging from "too dry" (-1) to "too humid" (+1).

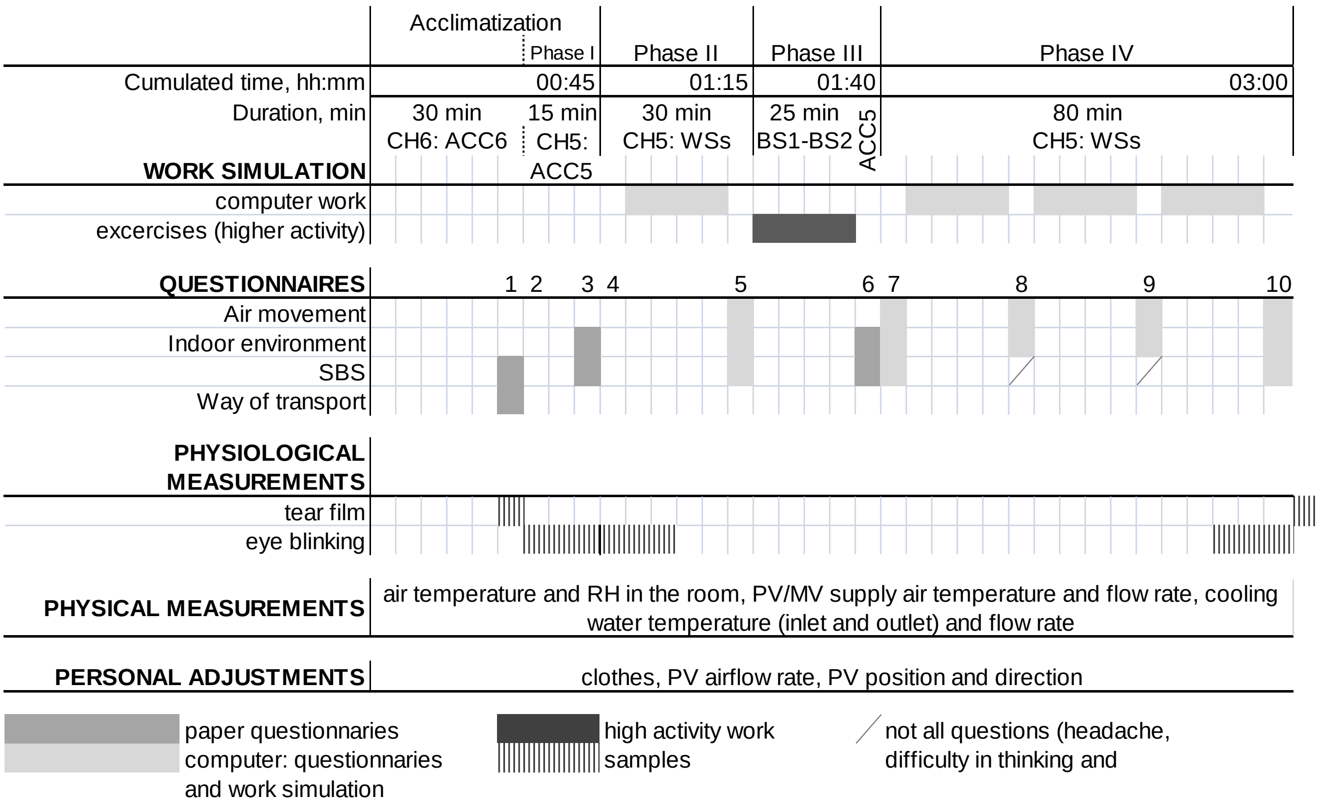

Figure 2. *Procedure during the exposure session*

The obtained results were statistically analysed. For the normality distribution testing Shapiro-Wilk's W-test was used. ANOVA tests and Newman Keuls tests were applied to normally distributed data. For remaining data Friedman ANOVA and Wilcoxon Matched Pair tests were used.

Velocity profiles from the RMP were measured with omnidirectional anemometers with an accuracy of 0,02 m/s ±1% of readings. Measurements were performed in a 35 x 35 cm grid (5 cm distance between measuring points) 40 cm from the diffuser, which is the typical distance from the face set by subjects. Measurements were conducted after human subjects' experiments without people presence.

3 Results and discussion

Eye dryness increased in time for all analysed systems (Figure 3a). During exposures at WSs with computers the eye dryness was evaluated at the moderate level of 45-65% and was significantly lower during relaxed ocular activity outside the WSs (15-35%) for all cases. The highest intensity of eye dryness was evaluated at CCMV26 at the end of Phase II. It was significantly higher than with both conditions at 28°C. No other significant differences between systems were found. Presented results indicate that the eye dryness intensity was influenced by the change of ocular tasks and use of computers at WSs, not by the elevated air movement from the PV.

Figure 3b presents number of subjects complaining on eye irritation for all studied cases. Shaded area shows number of subjects who perceived ocular irritation in the chamber 6 during the acclimatization process. It can be noted that initially temperature 28°C caused slightly higher number of irritation complaints. Number of complaints does not differ substantially between analysed cases. It was observed that at CCMV26 the eye irritation consequently increased in time, while at other systems it increased mainly during exposure at WSs. These data correspond to the eye dryness sensation rating. The highest number of 10 subjects who complained about ocular irritation was noted at the end of exposure during CCMV28 case.

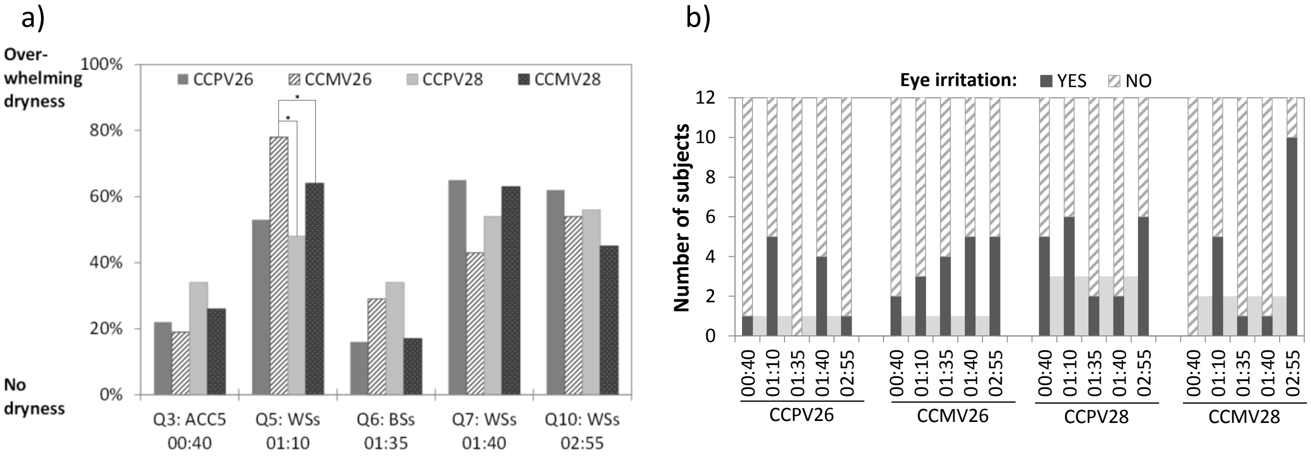

Figure 3. *Subjective measurements: a) eye dryness (significant at: * p<0,05; ** p<0,01; *** p<0,001), b) eye irritation (shaded area shows number of subjects declaring eye irritation before exposure)*

Air velocity is considered as one of the main environmental factors that can influence the eye dryness and irritation sensation. The airflow rates were used in a wide range which corresponded to air velocity in range from below 0,2 m/s up to almost 1,1 m/s (Figure 4a). Presented results suggest that elevated air movement from PV system has negligible impact on those symptoms. Probably due to possible individual control of supplied air flow rate, subjects were able to find right setting to experience the cooling effect and avoid possible eye irritation. Additionally subjects had a possibility of changing RMP's position which determines direction of airflow. The preferable flow direction was toward the face (56-63%), even when most often used airflow rates resulted in velocities above 0,8 m/s in the ocular region. Figure 4b shows subjects' votes on air movement. Majority of subjects assessed air movement with CCPV system as acceptable (88-100%) and declared "no change" (54-84%). "Less air movement" votes appeared only at cases with CCPV, which may be a result of using higher than preferable airflows to keep thermal sensation lower than "slightly warm". Nevertheless no correlation between eye irritation and air movement acceptability nor preferable changes in air movement were found. With CCMV system large number of subjects complained of insufficient air movement: 50-75% at 26°C and 80-95% at 28°C. The air movement acceptability was the lowest at CCMV28 case and was in the range of 45-65%.

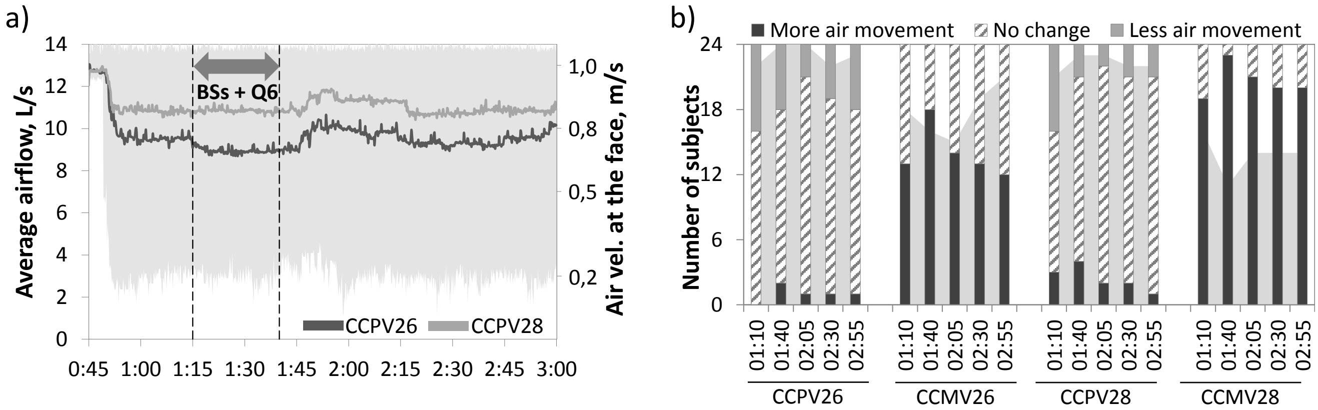

Figure 4. *Air movement in time of exposure: a) average supplied PV airflow (shaded area shows range between maximal and minimal used flows) with translation into air velocity at the face, b) subjective votes air movement preference and acceptability – acceptable (shaded area) and not acceptable*

The results on PTF crystallization for all four conditions, organized into 5 groups are shown in Figure 5a. Grade 0 corresponds to the best and IV the worst category. Both cases with CCPV system characterized with the highest number of samples in grade 0 and the lowest in grade IV . When grades 0 and I are considered as a "good quality" (corresponding to healthy eye), grade II as a "neutral quality", grades III and IV as a "bad quality" (unhealthy eye), it can be seen that cases CCMV26 and CCPV28 performed at the similar level. If individual change in 5-grade scale between sample taken during acclimatization and at the end of exposure is analysed, the CCPV28 case is characterized by the highest number of improvement in PTF crystallization pattern. One of the explanations why CCPV28 performed better than CCPV26 is that at the temperature of 28°C the airflow rates used by subjects were higher than at 26°C. This resulted in bigger temperature difference between the facial and ambient regions. It can be assumed that use of cool and clean air decreases the negative effect of high room temperature on PTF quality, even on elevated air velocity. Present results confirmed previous findings of studies on the PV (Melikov et al., 2013b).

Figure 5b presents average BF depending on the analysed cases. At all systems the highest BF appeared during relaxing activity and later dropped at the WSs, where subjects were performing computer tasks. No significant differences in BF were found between beginning and end of exposure at the WSs. Obtained results are within normal ranges for those ocular activities: 7-10 blinks/min for computer tasks and 13-20 blinks/min during relaxation (Wolkoff et al., 2003). No correlation between BF and eye dryness nor PTF quality were found. Both eye dryness sensation and BF were, however, related to ocular activity and use of computer monitor.

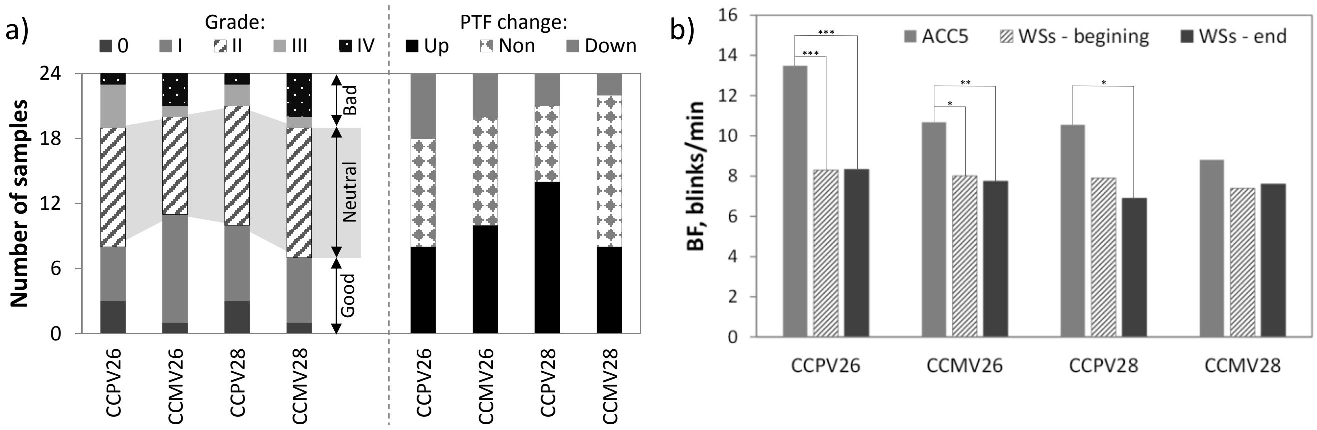

Figure 5. *Physiological measurements of ocular symptoms: a) pre-corneal tear film quality at the end of exposure and its' change comparing to acclimatization state; b) blinking frequency (significant at: * p<0,05; ** p<0,01; *** p<0,001)*

The RH in the experiment room varied slightly between sessions, but always within the range of 20 to 30%. The air dryness was evaluated by subjects at similar level of approximately -0,2 (on scale: -1: too dry, +1 – too humid)for all studied cases .

4 Conclusions

The main conclusion of this study is that individually controlled elevated air movement from PV system has negligible impact on the ocular symptoms. It did not result in significantly higher eye dryness and irritation sensation compared to the MV air distribution. Eye dryness and blinking frequency were influenced by the ocular activity, not by the used ventilation system. Use of cool personalized airflow improved the pre-corneal tear film stability at the high room air temperature of 28°C.

Use of individual control of supplied PV airflow resulted in creating preferable and acceptable air movement by most of the subjects. It is claimed that this is one of the main solutions to avoid possible eye irritation caused by elevated air movement.

5 Acknowledgments

This research was performed at the International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark. It was funded by Aleksandra Lipczynska’s scholarship under the "DoktoRIS – Scholarship programme for innovative Silesia" (co-financed by the European Union under the European Social Fund covered by Human Capital Programme) and by the International Centre for Indoor Environment and Energy.

6 References

15251, 2007, *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*, Brussels, European Committee for Standardization.

Bolashikov, Z., L. Nikolaev, A. Melikov, J. Kaczmarczyk, and P. Fanger, 2003, *New air terminal devices with high efficiency for personalized ventilation application*, Healthy Buildings 2003, p. 850-955.

Kaczmarczyk, J., A. Melikov, and P. Fanger, 2004, *Human response to personalized ventilation and mixing ventilation*, Indoor Air, v. 14, p. 17-29.

Kaczmarczyk, J., A. Melikov, and D. Sliva, 2010, *Effect of warm air supplied facially on occupants' comfort*, Building and Environment, v. 45, p. 848-855.

Lipczynska, A., J. Kaczmarczyk, and A. Melikov, 2014a, *Performance of personalized ventilation combined with chilled ceiling in an office room: inhaled air quality and contaminant distribution*, Indoor Air 2014.

Lipczynska, A., J. Kaczmarczyk, and A. Melikov, 2014b, *Performance of radiant cooling ceiling combined with personalized ventilation in an office room: identification of thermal conditions*, Indoor Air 2014.

Masmali, A. M., P. J. Murphy, and C. Purslow, 2014, *Development of a new grading scale for tear ferning*, Contact Lens & Anterior Eye, v. 37, p. 178-184.

Melikov, A., B. Krejcirikova, J. Kaczmarczyk, M. Duszyk, and T. Sakoi, 2013a, *Human response to local convective and radiant cooling in a warm environment*, HVAC&R Research, v. 19, p. 1023-1032.

Melikov, A., V. Lyubenova, M. Skwarczynski, and J. Kaczmarczyk, 2011, *Impact of air temperature, relative humidity, air movement and pollution on eye blinking*, Indoor Air 2011.

Melikov, A. K., M. A. Skwarczynski, J. Kaczmarczyk, and J. Zabecky, 2013b, *Use of personalized ventilation for improving health, comfort, and performance at high room temperature and humidity*, Indoor Air, v. 23, p. 250-263.

Schiavon, S., and A. Melikov, 2008, *Energy saving and improved comfort by increased air movement*, Energy and Buildings, v. 40, p. 1954-1960.

Schiavon, S., A. Melikov, and C. Sekhar, 2010, *Energy analysis of the personalized ventilation system in hot and humid climates*, Energy and Buildings, v. 42, p. 699-707.

Skotte, J. H., J. K. Nojgaard, L. V. Jorgensen, K. B. Christensen, and G. Sjogaard, 2007, *Eye blink frequency during different computer tasks quantified by electrooculography*, European Journal of Applied Physiology, v. 99, p. 113-119.

Wolkoff, P., 2005, *An integrated approach to eye irritation in the office - Importance of the relative humidity?*, Indoor Air 2005: Proceedings of the 10th International Conference on Indoor Air Quality and Climate, Vols 1-5, p. 3777-3781.

Wolkoff, P., 2008, *"Healthy" eye in office-like environments*, Environment International, v. 34, p. 1204-1214.

Wolkoff, P., J. K. Nojgaard, C. Franck, and P. Skov, 2006, *The modern office environment desiccates the eyes?*, Indoor Air, v. 16, p. 258-265.

Wolkoff, P., P. Skov, C. Franck, and L. N. Petersen, 2003, *Eye irritation and environmental factors in the office environment - hypotheses, causes and a physiological model*, Scandinavian Journal of Work Environment & Health, v. 29, p. 411-430.

Wyon, N. M., and D. P. Wyon, 1987, *Measurement of acute response to draft in the eye*, Acta Ophthalmologica, v. 65, p. 385-392.